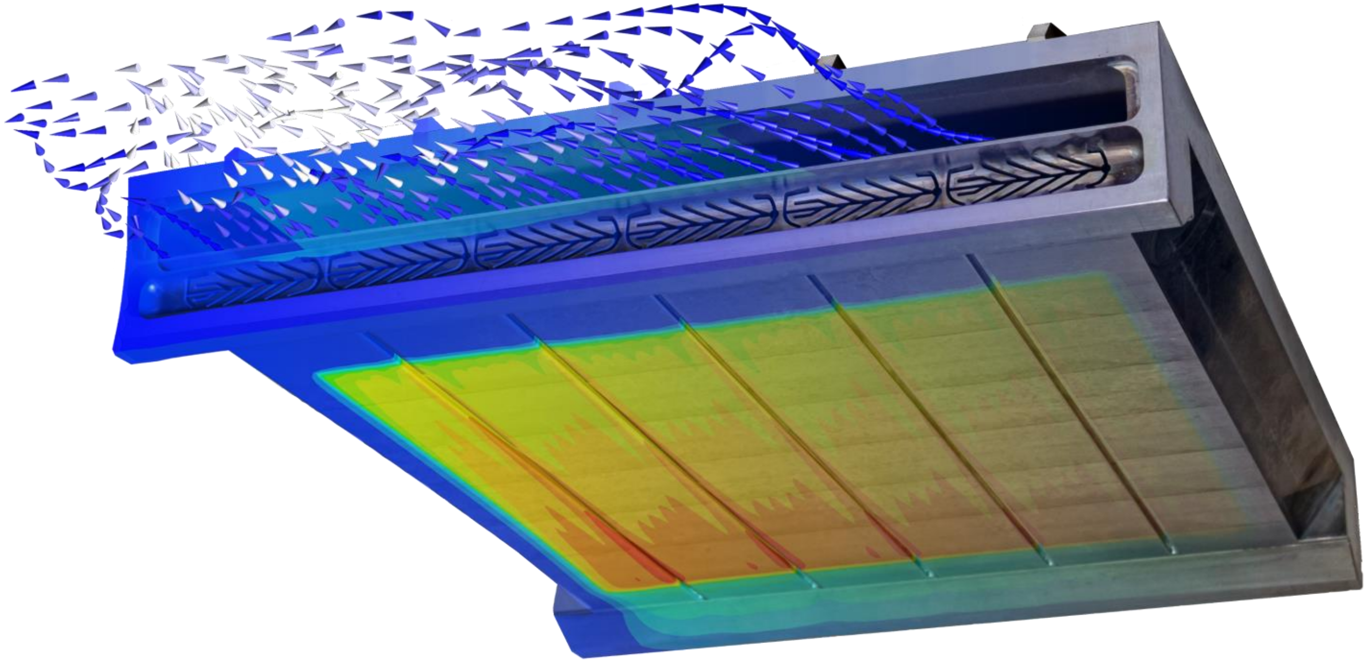


HBS Tantalum Target Development for Neutron Production at HiCANS

International Workshop on future research program with the high power Cyclotron of SPES-LNL

13th May 2025 I Johannes Baggemann, Eric Mauerhofer, Thomas Gutberlet, Jingjing Li, Ulrich Rücker, Paul Zakalek

JÜLICH
Forschungszentrum

JCNS – Jülich Centre for Neutron Science

Neutrons for Users

Mitglied der Helmholtz-Gemeinschaft

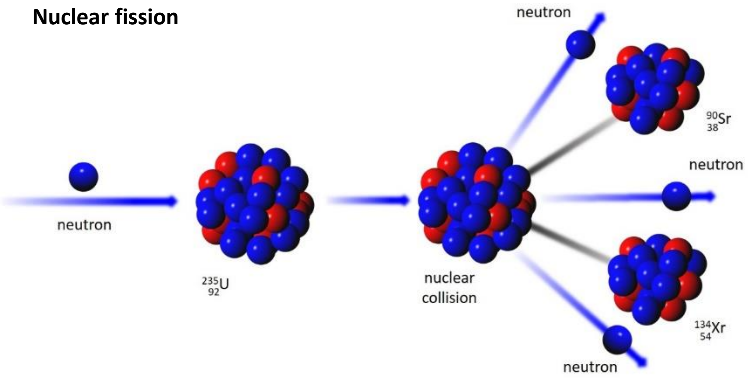
Institute Laue-Langevin
1+2 Instruments operated by 3 employees
(IN12, D23, IN22)

Heinz Maier-Leibnitz Zentrum
11 instruments operated (2 from RWTH Aachen),
2 ready for commissioning

European Spallation Source
Jülich contributes to the design and construction of 4 instruments

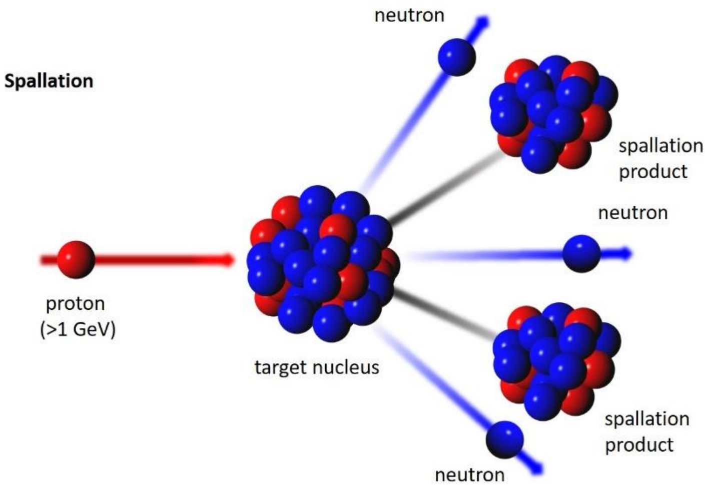
NEUTRON PRODUCTION

Nuclear fission



Reactor based neutron source
(ILL, FRM II, NIST, JINR, ANSTO a.m.m.)

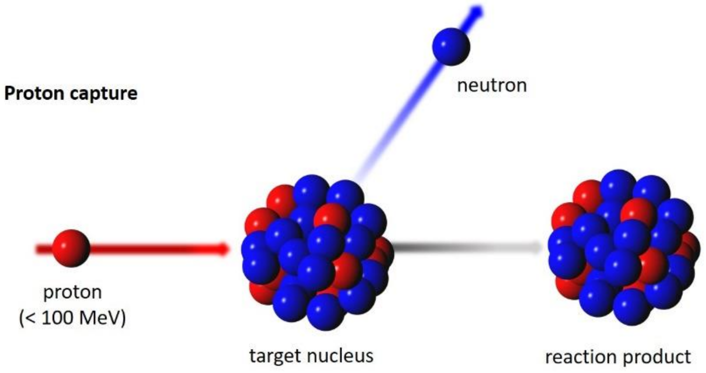
Spallation



Spallation based neutron source
(ESS, SNS, J-PARC, ISIS, SINQ, CSNS)

Ion Energy > 800 MeV
Stopping range: around 500 mm

Proton Capture

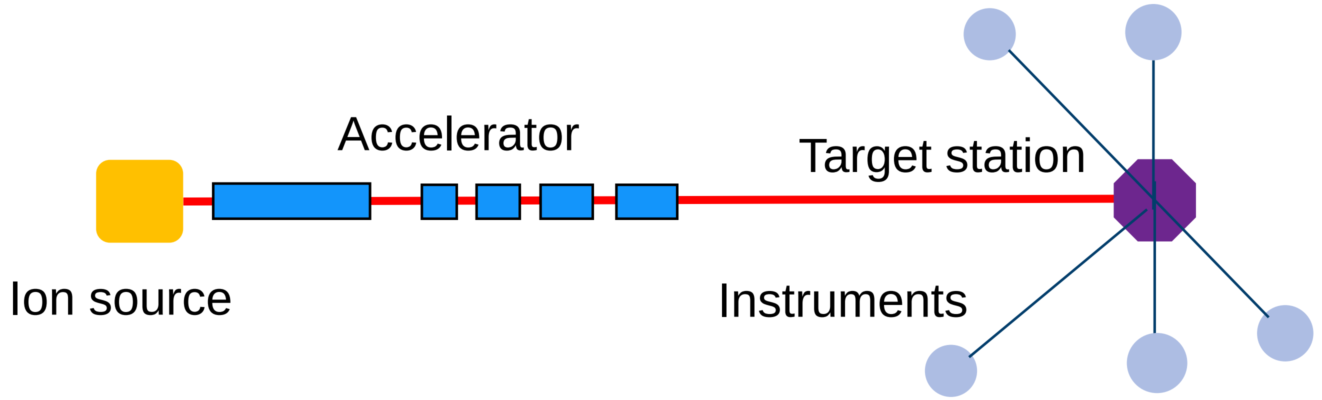


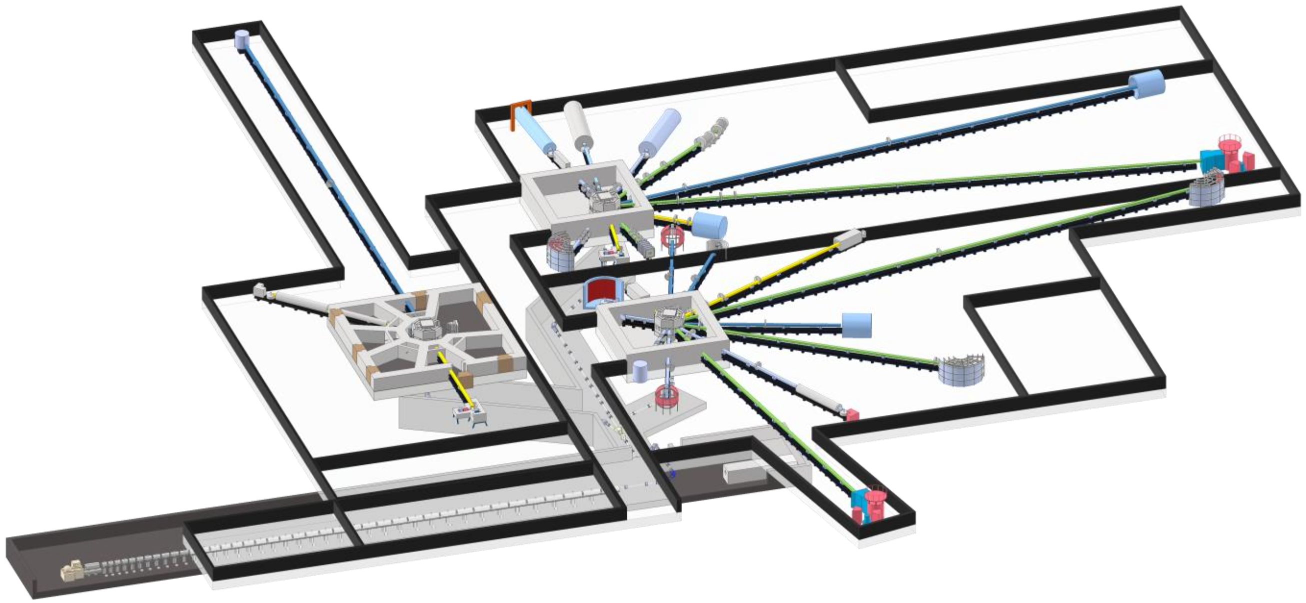
Accelerator based neutron source
(LENS, RANS, HUNS, NUANS, IREN, a.o.)

Ion Energy < 100 MeV
Stopping range: few millimeter

HIGH-CURRENT ACCELERATOR-DRIVEN NEUTRON SOURCE

AN INNOVATIVE APPROACH TO RELEASE NEUTRONS





- Energy in low MeV range
- High peak current
- Regional – national source
- Efficient neutron source
- Target multiplexing straight forward and affordable
- Large instrument suite possible

HBS (Germany)
ICONE (France)
ARGITU (Spain)
LENOS (Italy)

HBS: A HiCANS facility

High current linear accelerator

- 90 mA, 70 MeV pulsed proton beam
- Variable frequency

Several target stations

- Optimize pulse structure (length, rep. rate)
- Optimize thermal spectrum

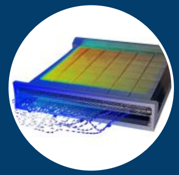
Small shielding

- Neutron guide close (~40 cm) to cold source
- Chopper at < 2 m from target

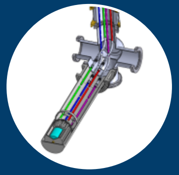
Every beam port serves only 1 Instrument

- Optimize cold source spectrum
- Optimize geometry
- Integrate neutron optics with beam port

Accelerator



Target



Moderators

Instrumentation

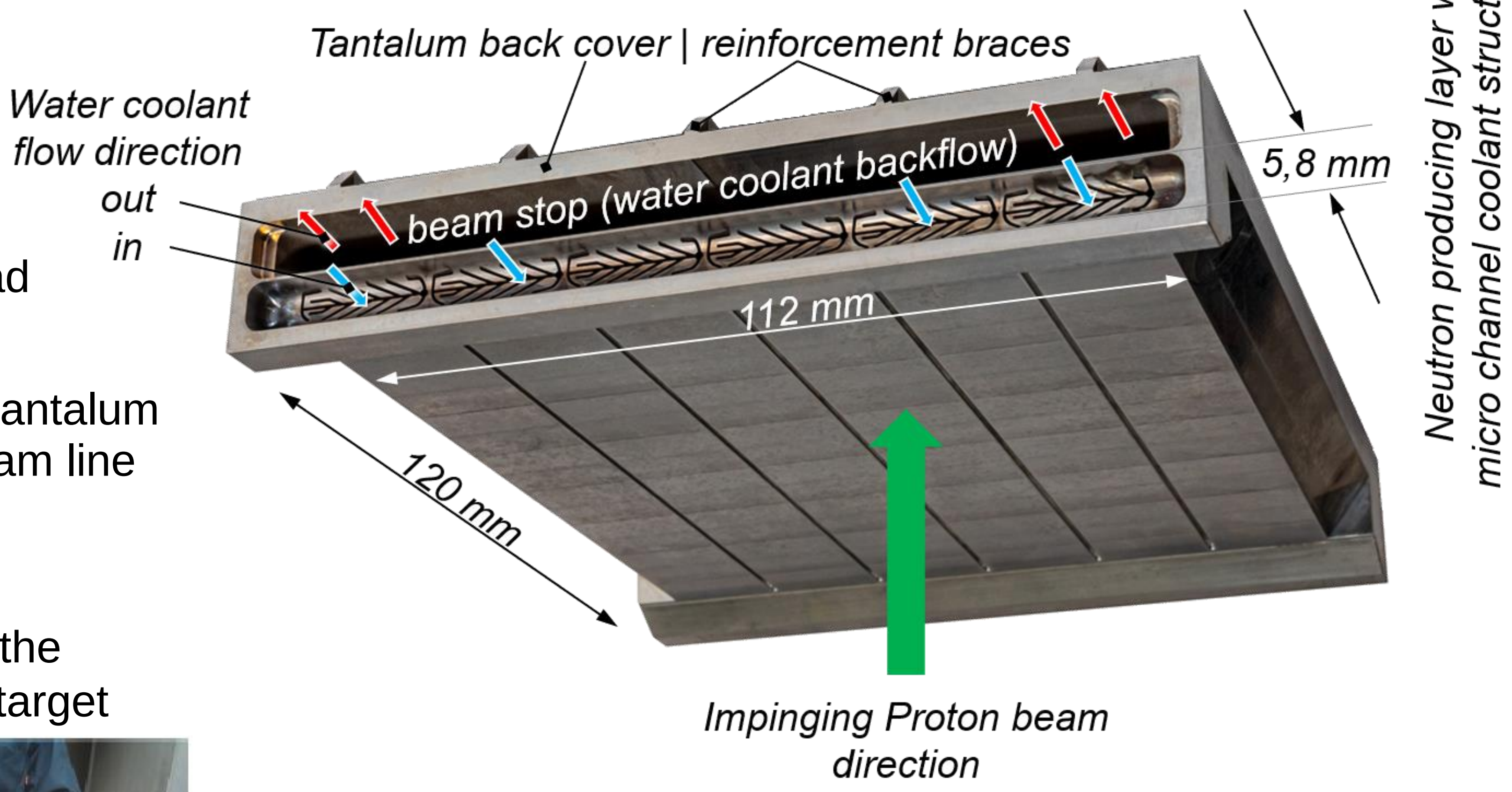
Holistic optimization*

*to compensate for the initial lower neutron yield

HBS Tantalum Target

- Designed to operate with
  - 70 MeV proton beam
  - 90 mA_{cw} proton current
  - 1.6 % duty cycle

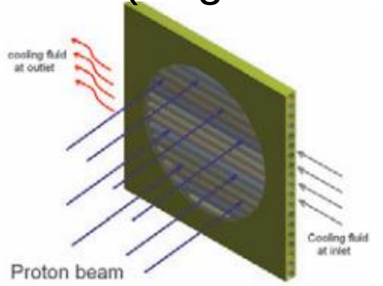
    → 100 kW pulsed thermal load



target fabricated out of a single piece tantalum to operate inside vacuum of proton beam line

- in total ~ 4 kg Tantalum

Microchannel Cooling is inspired by the LENOS (LEgnaro NeutrOn Source) target



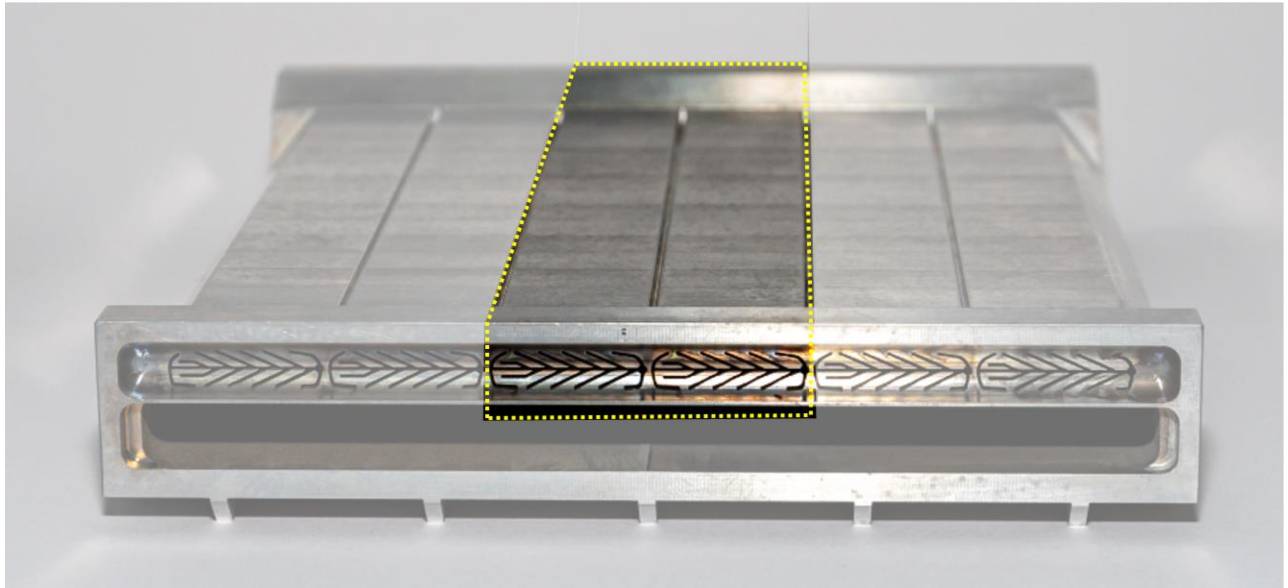
https://doi.org/10.1016/j.phpro.2012.03.034

What we would like to measure with high power Cyclotron of SPES-LNL

I) Measurement of the ratio of stopped to penetrated protons behind the first layer at 70 MeV in order to verify the effectiveness of the counter measure against hydrogen embrittlement

II) Angle dependent neutron spectrum of Tantalum at 70 MeV

III) Measurement of the temperature distribution on the back side of the target to verify the coolant capability at real operation conditions



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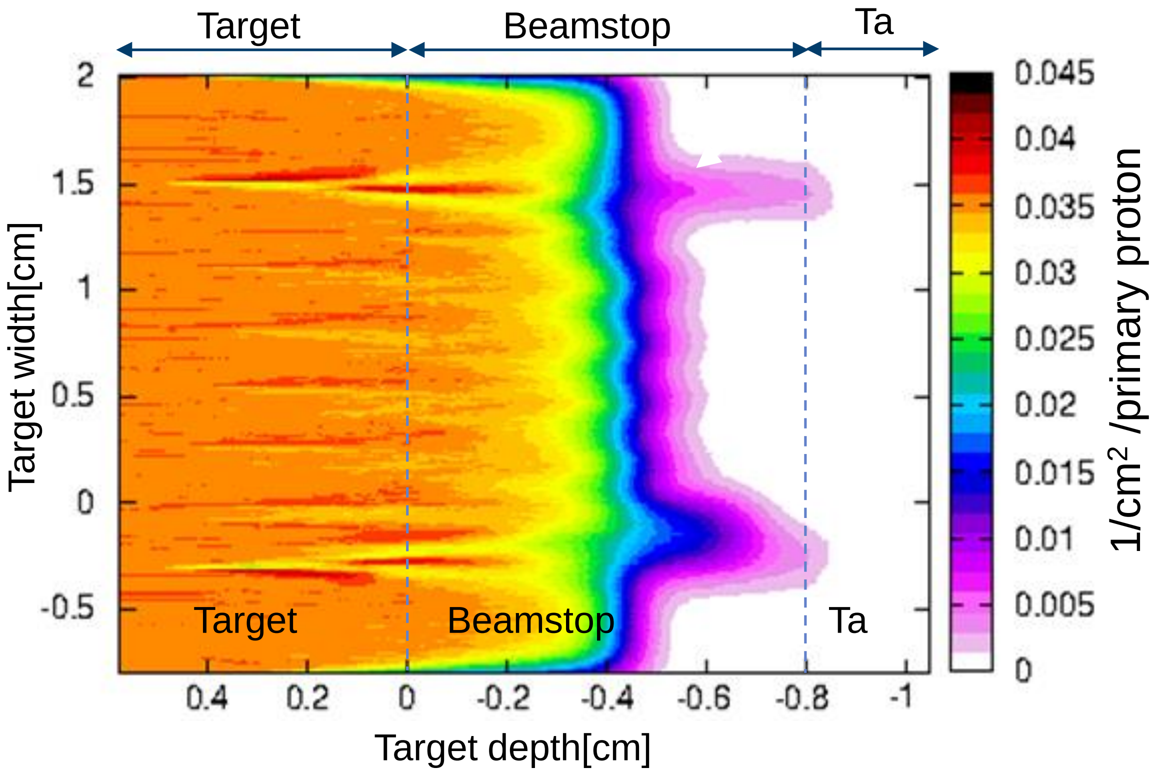
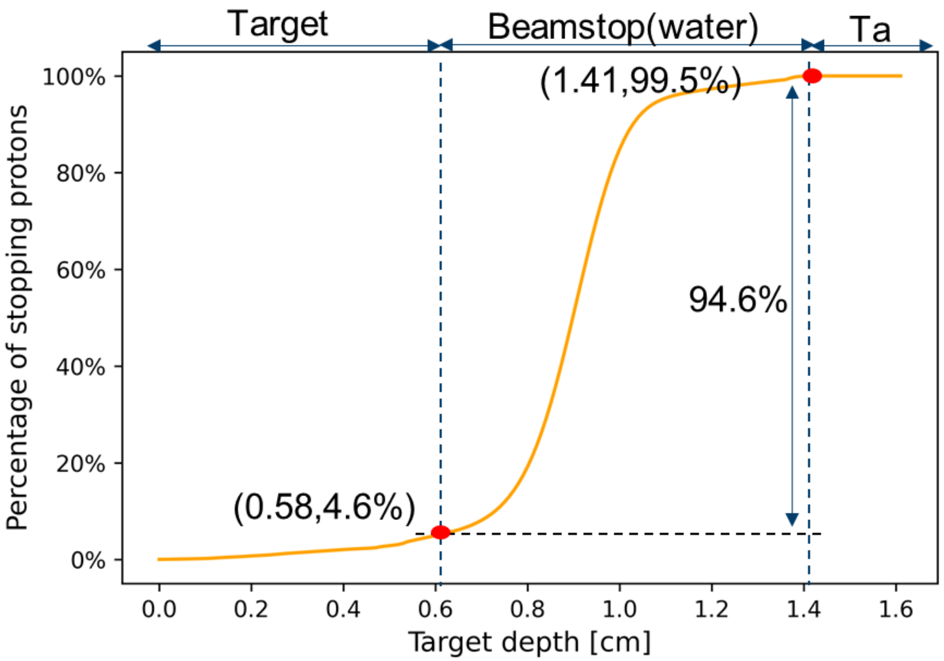
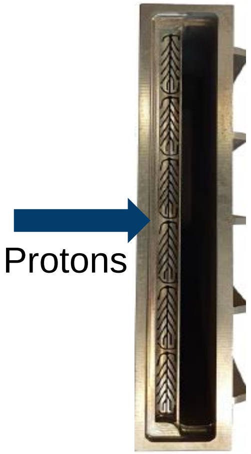
Proton fluence and energy deposition of one fishbone element

- Proton flux







- 4.6% of protons accumulate in the metal target
- 94.6% of protons stop in the beamstop
- 0.5% of protons stops in the Ta wall behind the beamstop
- Neutron production of this thin target can be as high as 99% of a thick target

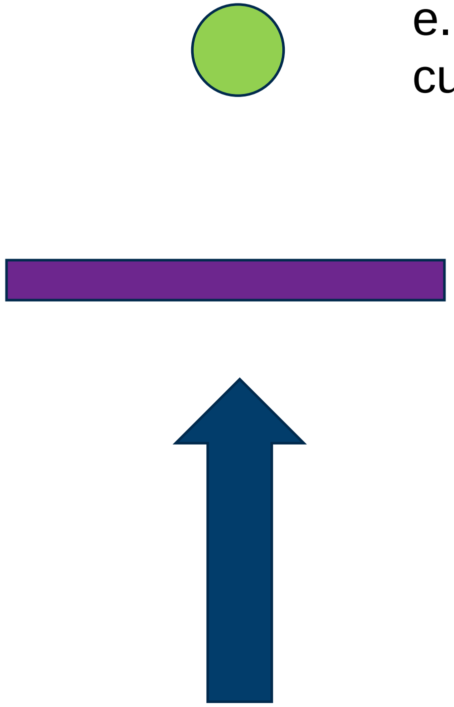
FLUKA 2020.0, cross section: ENDF/B-8R0 and JENDL40-HE

I) Measurement of the ratio of stopped to penetrated protons

blistering caused by hydrogen implantation is one of the major challenges in the development of CANS Tagets.

our main measures:
- target is made of tantalum which can
  - absorb a high amount of hydrogen (0.76 H/Ta atom) and
  - retains its properties up to 0.175 H/Ta atom
- Thickness of the target (tantalum and water) is smaller than the penetration thickness of 70 MeV protons

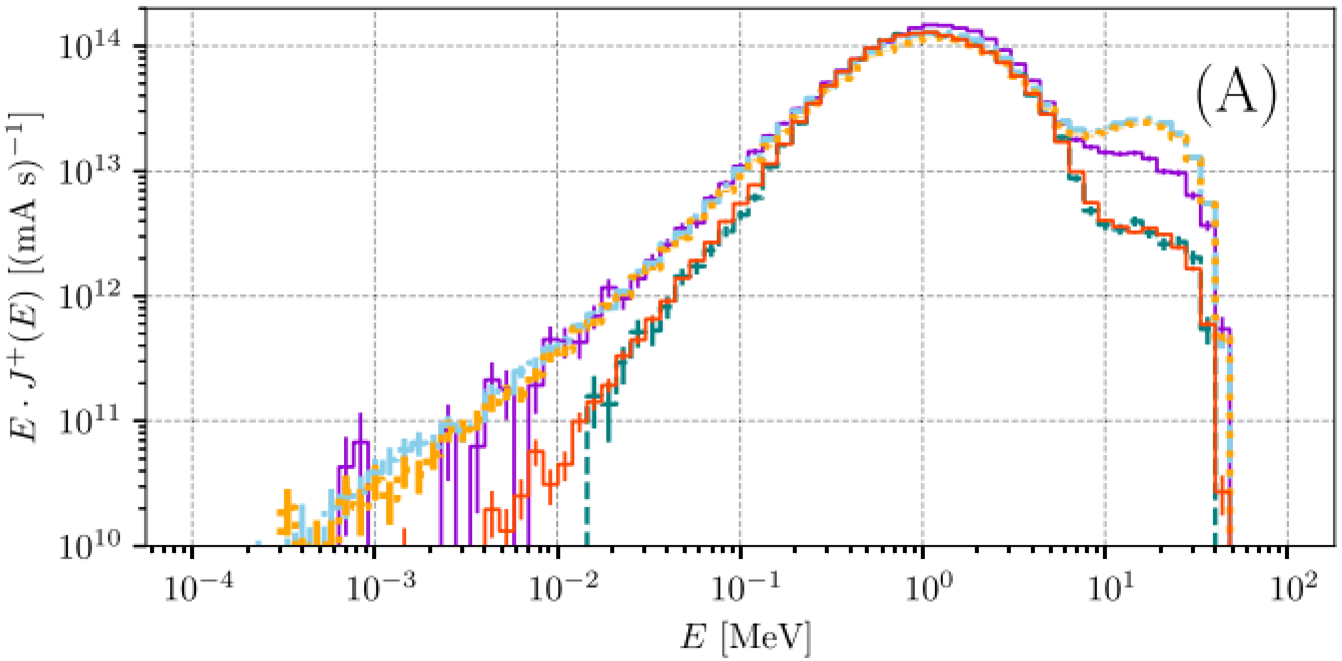
Proton flux measurement:
e.g. via measurement of the electric current at a massive metal plate



Target

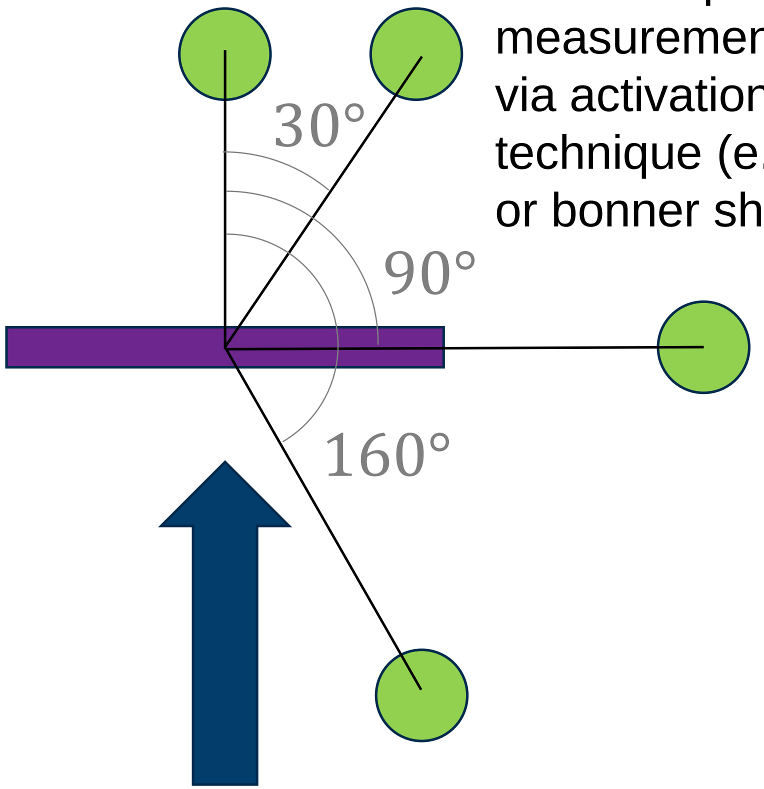
Proton beam
70 MeV
minor flux
beam diameter ~ 2 cm

II) Angle dependent neutron spectrum of Ta at 70 MeV



Total neutron spectra for a bare Ta target irradiated with 45 MeV protons, obtained with MCNP6 and PHITS along with different physical models and cross-section databases

Neutron spectra measurement via activation foil technique (e.g. Zr, Ti, Al) or bonner shere



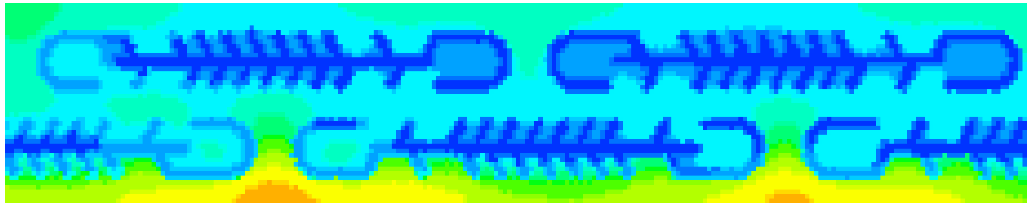
Proton beam
70 MeV
minor flux
beam diameter ~ 2 cm²

Experiment Testing of Cooling Performance

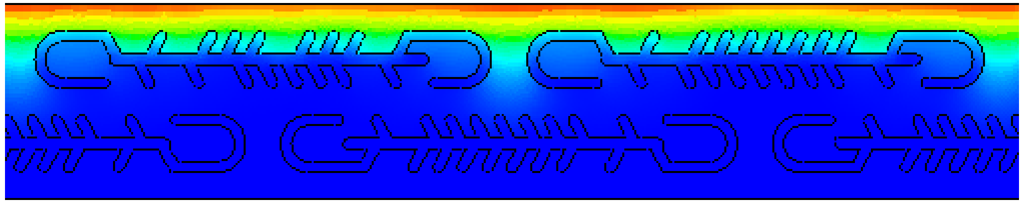
- Homogeneous beam scanning exposure of central area (8 x 6 cm²)
- stationary heat load in steps up to 10 MW/m² (1 kW /cm²) → 48 kW in total
- JUDITH-2 is an electron beam facility
  → Surface heating!

beam direction

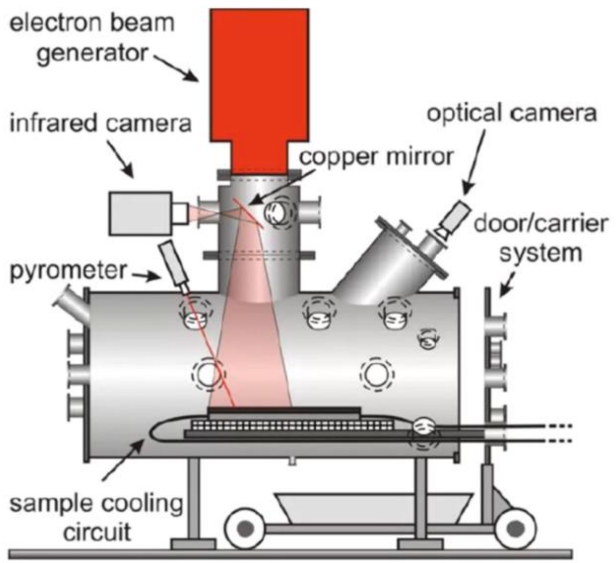
Proton beam heating



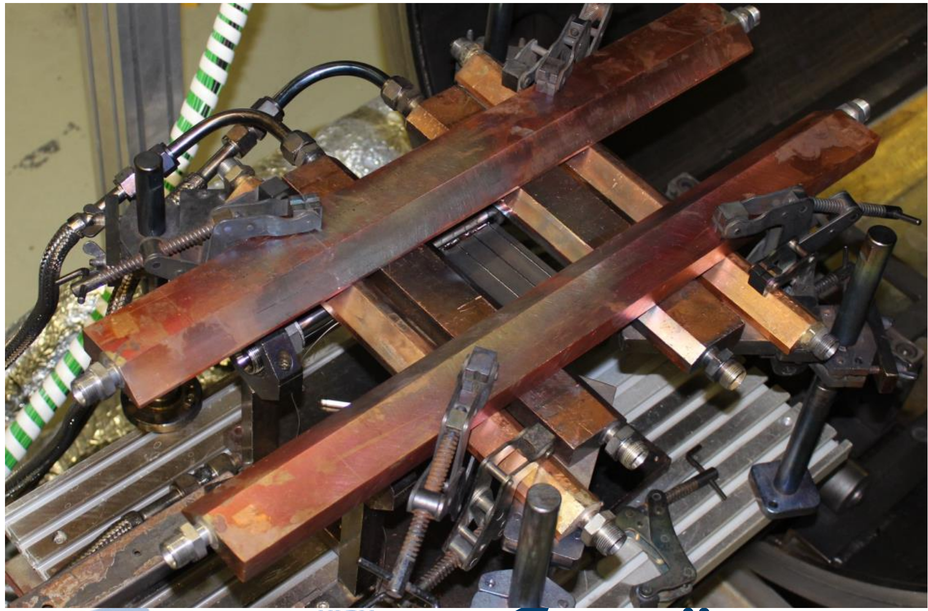
Electron beam heating



Exemplary temperature distribution from CFD



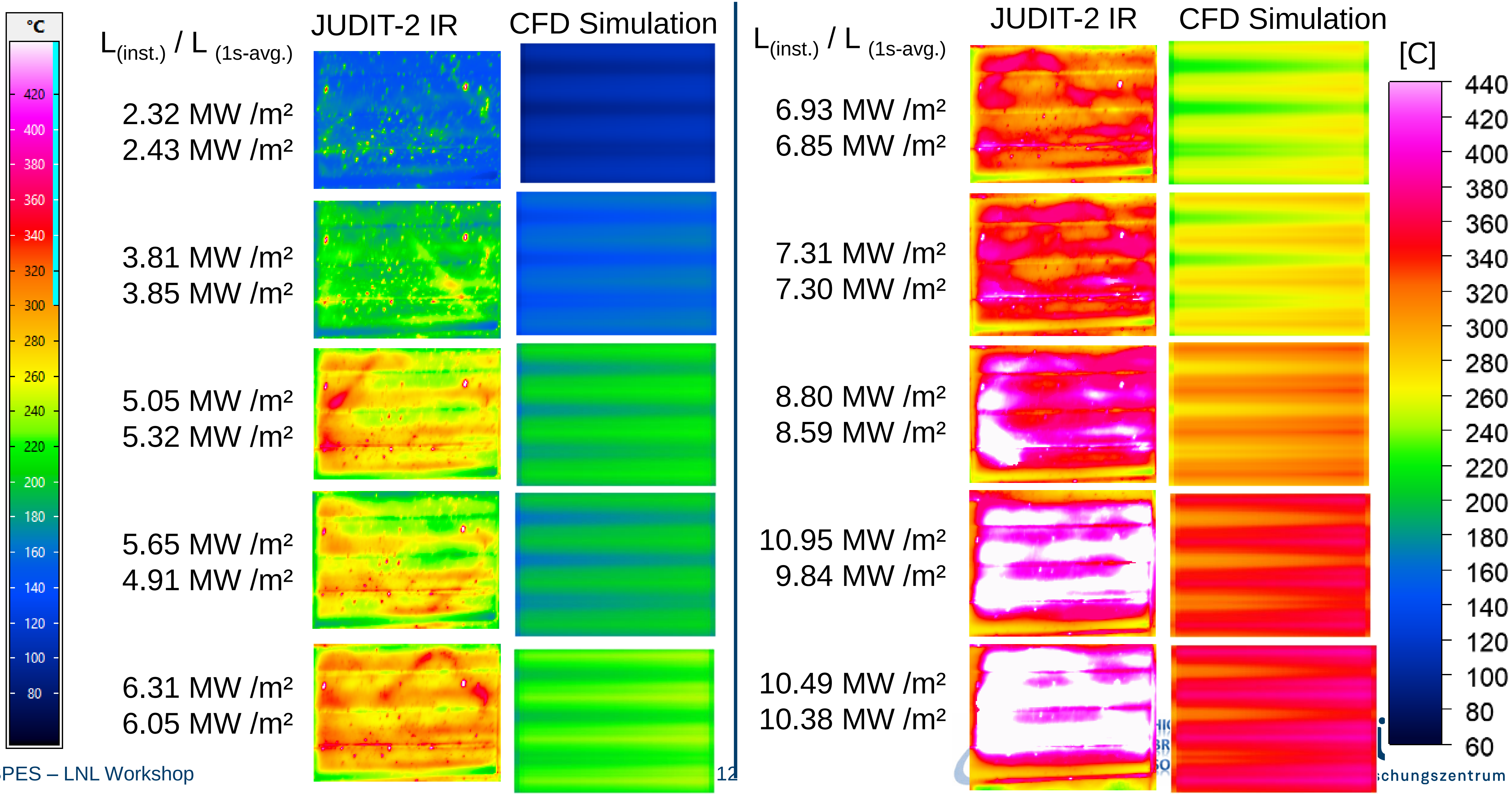
Judith-2 basic design [IEK-4]



HBS target inside JUDITH-2

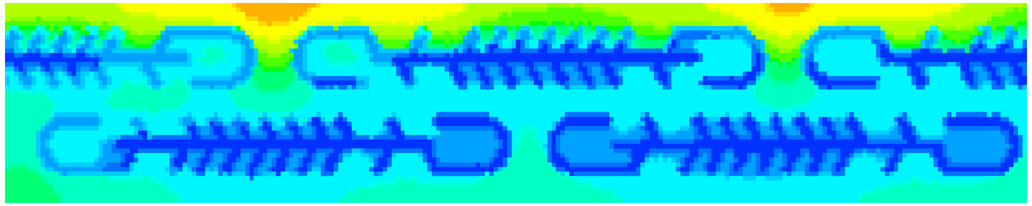
- only about a quarter of the coolant interface area contributes to the heat removal in case of electron gun heating
- → very conservative heat load conditions at experiment

Comparison of CFD Simulation and Experimentas

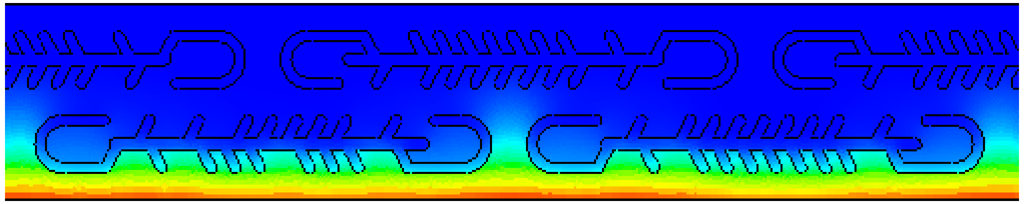


III) Temperature distribution on the back side of the target

Proton beam heating

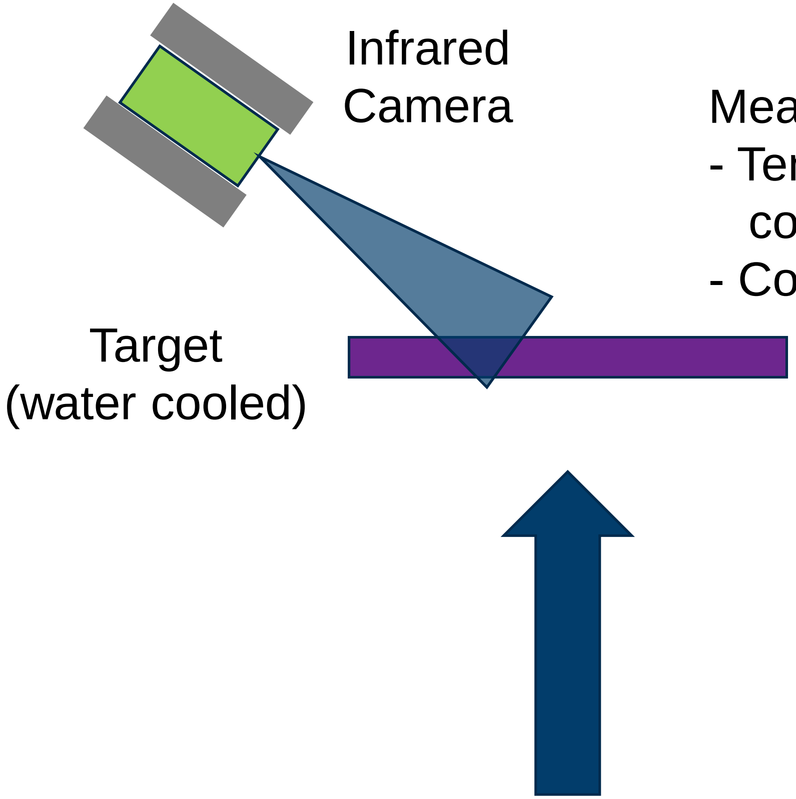


Electron beam heating



Exemplary temperature distribution from CFD

beam
direction



Measurement:
- Temperature increase of coolant water
- Coolant mass flow

Proton beam
70 MeV
14.4 µA /cm²
A > 86.4 µA resp. 8 cm²

Summery:
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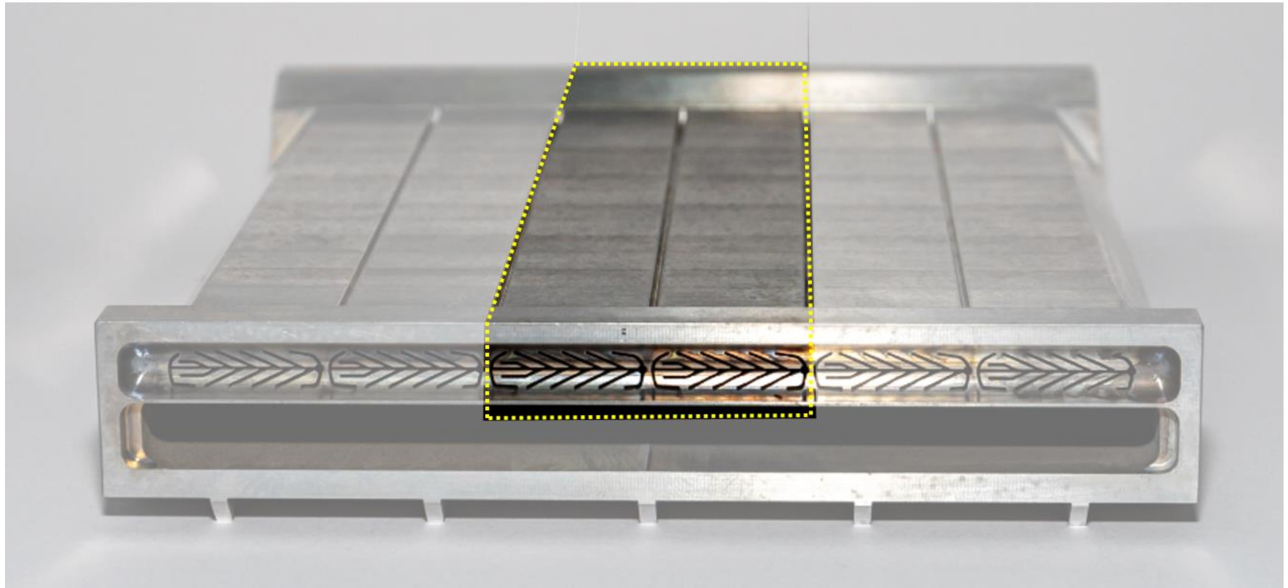

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- Accelerator

/ HIM

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- Accelerator

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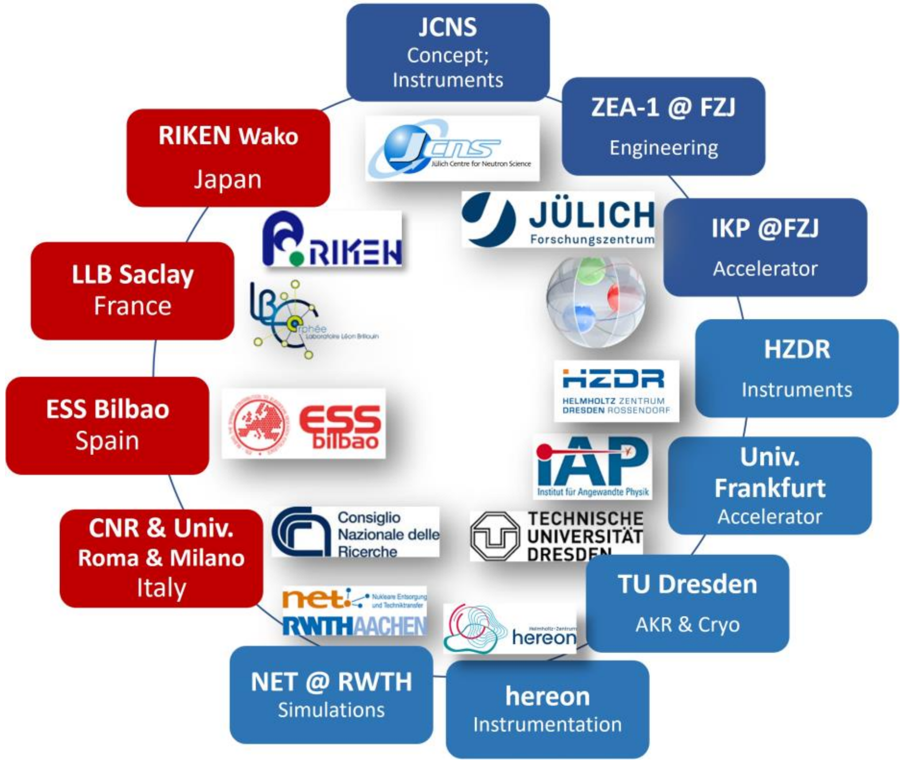
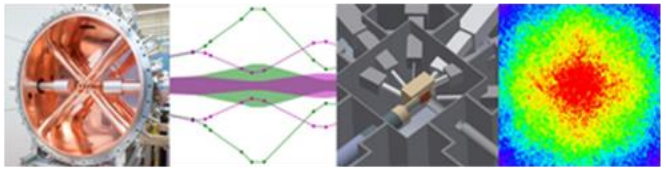
- JULIC Neutron Platform Experiments



HBS Innovationpool Project



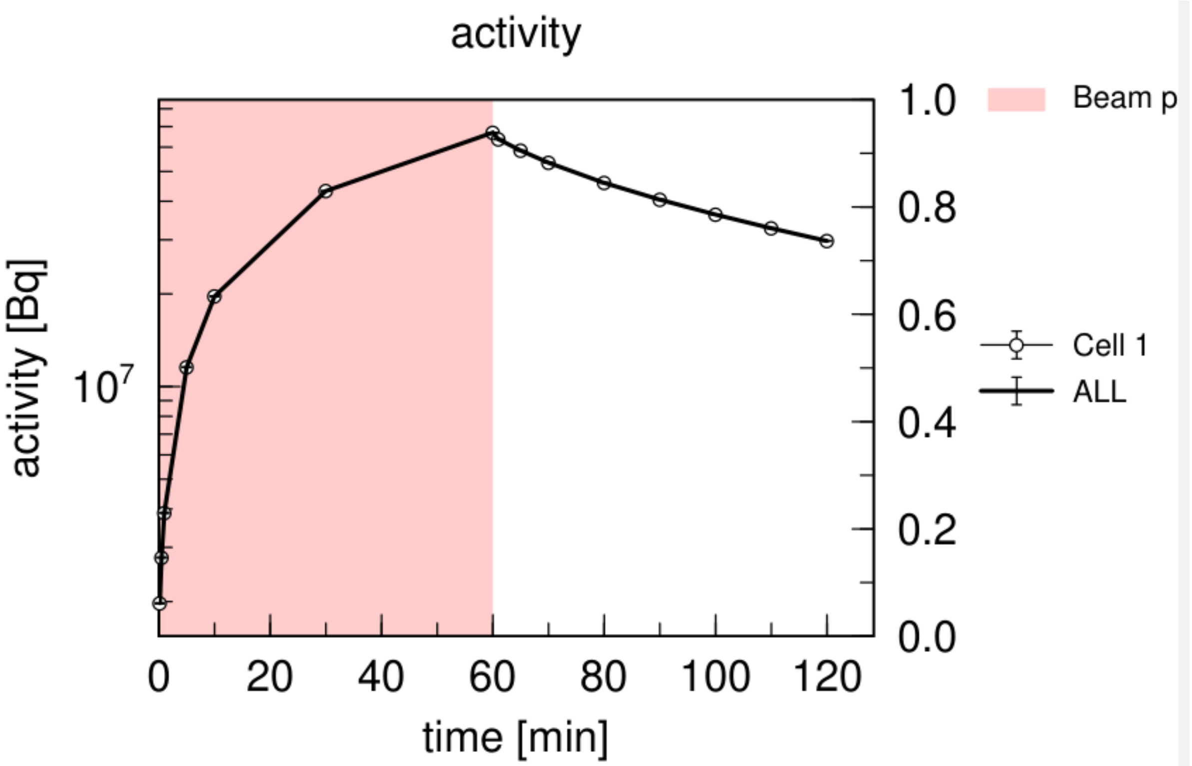
Federal Ministry of Education and Research

FB Matter: MML, MT

Backup

Induced radioactivity from 70 MeV protons on tantalum target

- Target geometry (cylinder)
  - Thickness: 0.5 cm
  - Radius: 3.88 cm
  - 400 g Tantalum
- Proton beam
  - 70 MeV
  - 1 nA
  - Beam illuminated radius: 0.2 cm
  - Irradiation time: 1h
  - Decay time: 1h



Induced radioactivity from 70 MeV protons on tantalum target

Mitglied der Helmholtz-Gemeinschaft

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  - Thickness: 0.5 cm
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  - 400 g Tantalum
- Proton beam
  - 70 MeV
  - 1 nA
  - Beam illuminated radius: 0.2 cm
  - Irradiation time: 1h
  - Decay time: 1h

dominant nuclides (top 10)

no.	nuclide	Activity [Bq/cc]	[Bq]	rel. err.	[%]
1	W 179	1.1157E+06	2.6370E+07	5.1520E-03	39.44
2	W 179m	2.8557E+05	6.7494E+06	9.6020E-03	10.09
3	W 177	2.8070E+05	6.6343E+06	5.0330E-03	9.92
4	W 176	2.0967E+05	4.9556E+06	5.5130E-03	7.41
5	W 175	2.0128E+05	4.7572E+06	9.5340E-03	7.11
6	Hf178m	1.5874E+05	3.7518E+06	7.5981E-03	5.61
7	Ta178	1.5774E+05	3.7283E+06	6.5200E-03	5.58
8	Ta178m	1.3398E+05	3.1667E+06	1.3915E-02	4.74
9	Ta180	1.3287E+05	3.1403E+06	4.0998E-03	4.70
10	Ta182m	6.3144E+04	1.4924E+06	3.7164E-03	2.23

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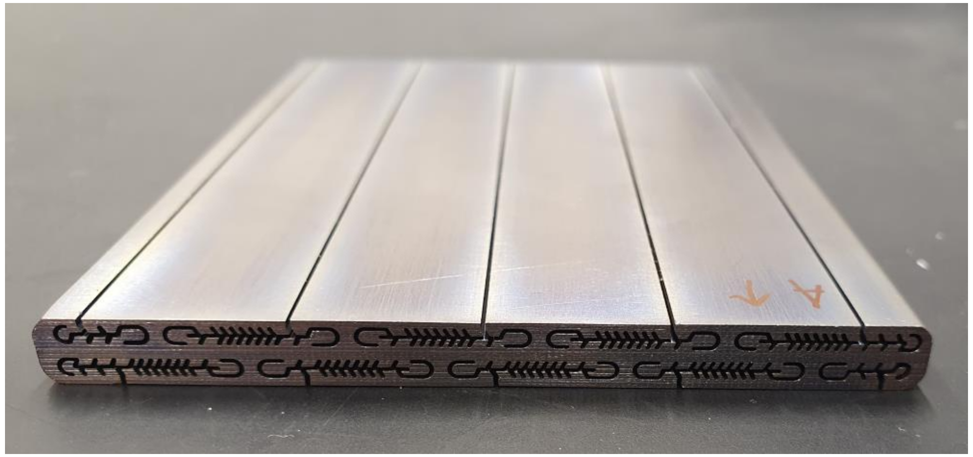
Improved fabrication process

Sinker EDM and wire erosion (EMD) process



Eroded holes via sinker EDM as starting points for wire EDM

→ No welds on the surface

→ No clogged micro channels from the weld

→ No twisted micro channels

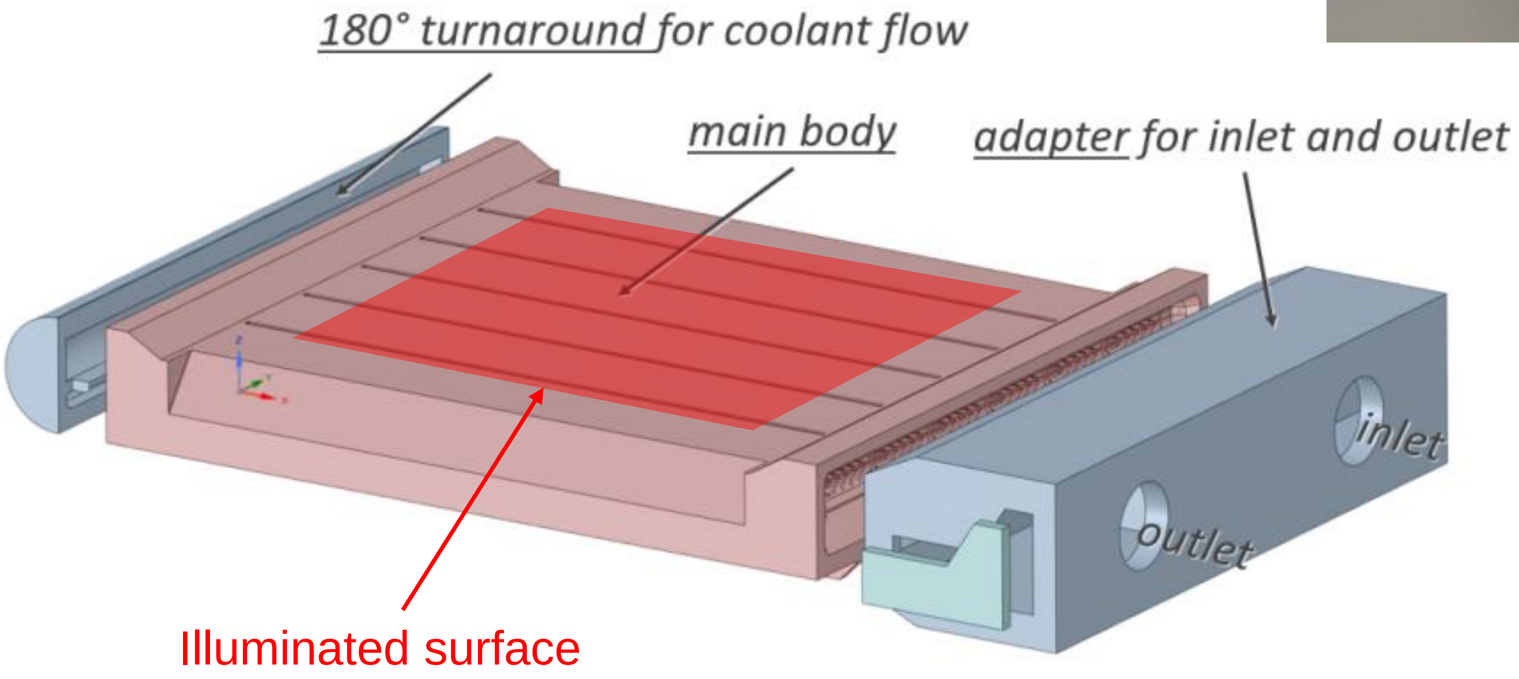
→ No welding inside the proton beam

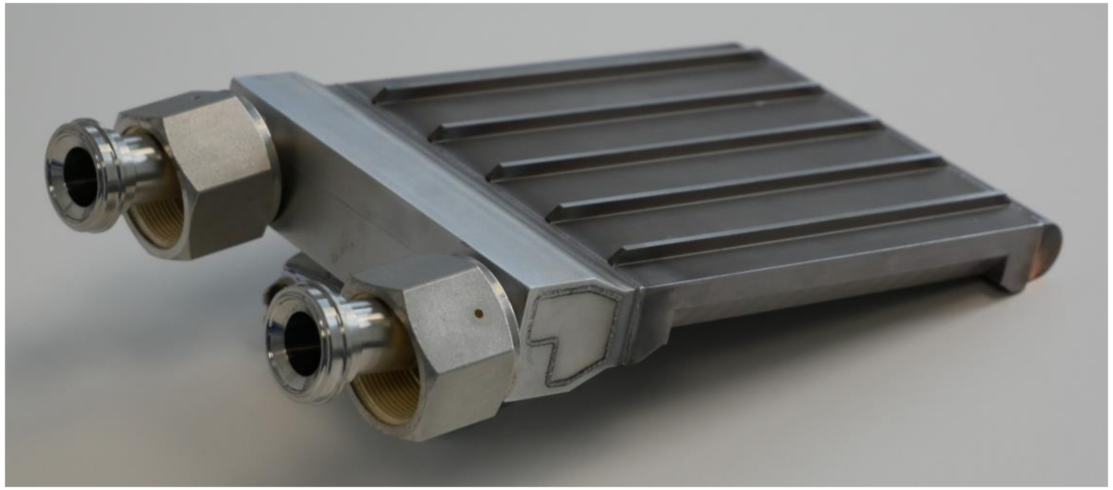
diameter:0.6 mm

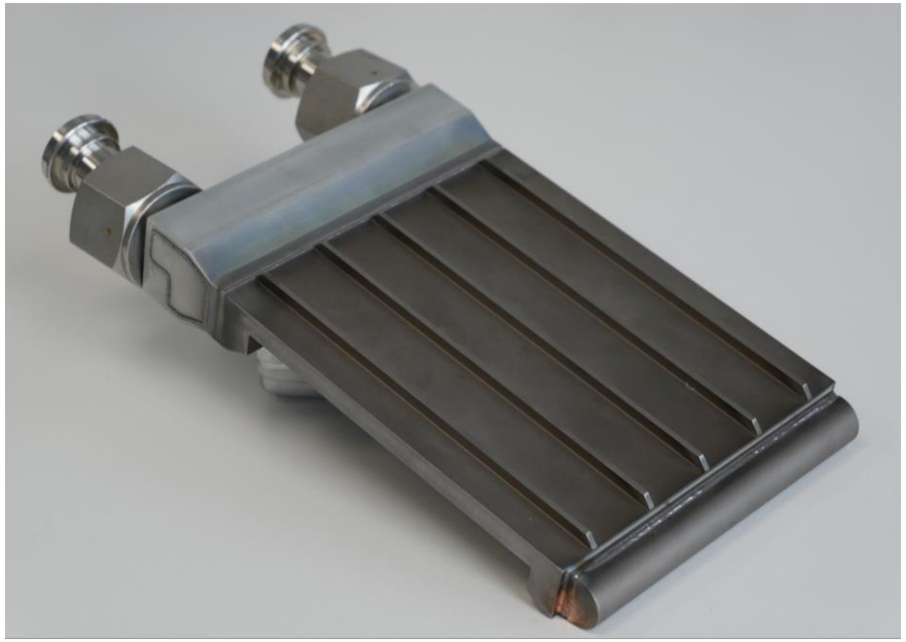
Fabrication at JCNS-PGA-TA and ZEA

Target consists of 3 parts

- Main body made out of one single piece
- Welds between the three parts outside proton beam







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